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Comparing two biological indexes using benthic macroinvertebrates: positive and negative aspects of water quality assessment

Comparando dois índices biológicos utilizando macroinvertebrados bentônicos: aspectos positivos e negativos na avaliação da qualidade da água

Vinicius Moraes Rodrigues[1], Eliane Pintor de Arruda[2]*, André Cordeiro Alves dos Santos[3] and Monica Jones Costa[4]

[1]Programa de Pós-graduação em Biotecnologia e Monitoramento Ambiental, Centro de Ciências e Tecnologia para a Sustentabilidade, Universidade Federal de São Carlos – UFSCar, Campus Sorocaba, Rodovia João Leme dos Santos, Km 110, CEP 18053-780, Sorocaba, SP, Brazil

[2]Laboratório de Estudos de Macroinvertebrados Bentônicos, Departamento de Biologia, Centro de Ciências Humanas e Biológicas, Universidade Federal de São Carlos – UFSCar, Campus Sorocaba, Rodovia João Leme dos Santos, Km 110, CEP 18053-780, Sorocaba, SP, Brazil

[3]Laboratório de Microbiologia Ambiental, Departamento de Biologia, Universidade Federal de São Carlos – UFSCar, Campus Sorocaba, Rodovia João Leme dos Santos, Km 110, CEP 18053-780, Sorocaba, SP, Brazil

[4]Laboratório de Fisiologia da Conservação, Departamento de Biologia, Universidade Federal de São Carlos – UFSCar, Campus Sorocaba, Rodovia João Leme dos Santos, Km 110, CEP 18053-780, Sorocaba, SP, Brazil

*e-mail: arruda@ufscar.br

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Abstract: Aim: The aim of the present study, was to apply two biological indexes based on benthic macroinvertebrates (BMWP and ICB $_{RES-P}$) using as model the Itupararanga Reservoir to know what the advantages and disadvantages of the application of each index in that environment. **Methods:** The methodology consisted on three stages: 1) macroinvertebrates sampling and determination of limnological variables *in situ*, and sorting of the organisms in laboratory, 2) taxonomic identification of organisms and 3) determination of the saprobic degree for the collection sites and effectiveness of the application of the BMWP (Biological Monitoring Working Party score system) index and the Benthic Community Index created by CETESB (Environmental Sanitary Company of State of São Paulo) for deep regions (ICB $_{RES-P}$ index). **Results:** The study was performed over two periods (spring/summer and autumn/winter), and 8,841 organisms were sampled and divided in 17 families. The Chaoboridae (genus *Chaoborus*), Chironomidae (subfamilies Chironominae and Tanypodinae) and Tubificidae families had the most abundant taxa. The saprobic degree of the Itupararanga reservoir region resulted in the general classification of the reservoir as β-α mesasaprobic (βms- αms), considered critical due to its organic charge content. The BMWP index was adapted to the sample points and the scores subsequently obtained ranked the reservoir as category V, representing very poor water quality. The ICB $_{RES-P}$ index classified the sample points in the spring/summer period as having regular water quality, and the autumn/winter period as having good water quality. **Conclusions:** From previous findings, it can be concluded that further study and refinement of the components of both indexes are required in order to effectively assess the quality of water in reservoirs.

Keywords: biomonitoring; benthic macroinvertebrates; BMWP index; ICB $_{RES-P}$ index; Itupararanga Reservoir.

Resumo: Objetivo: O foco do presente estudo foi a aplicar dois índices biológicos, baseados nos macroinvertebrados bentônicos (BMWP e ICB $_{RES-P}$), utilizando o Reservatório de Itupararanga como modelo para determinar as vantagens e desvantagens na aplicação de cada índice nesse ambiente. **Métodos:** A metodologia consistiu em três etapas: 1) coleta de macroinvertebrados bentônicos, determinação *in situ* das variáveis limnológicas e triagem dos organismos em laboratório, 2) identificação taxonômica dos organismos e 3) determinação dos graus de saprobidade para os pontos de coleta e a eficácia da aplicação do Índice BMWP (Biological Monitoring Working Party score system) e do Índice de Comunidade Bentônica de região profundal (ICB $_{RES-P}$) criado pela CETESB (Companhia de Tecnologia de Saneamento Ambiental do Estado de São Paulo). Resultados: O estudo foi desenvolvido em dois períodos (primavera/verão e outono/inverno) onde 8.841 organismos foram coletados e divididos em 17 famílias. As famílias Chaoboridae (gênero *Chaoborus*), Chironomidae (subfamílias Chironominae e Tanypodinae) e Tubificidae foram os táxons mais abundantes. O grau de saprobidade obtido para a região do reservatório de Itupararanga, no geral, classificou o reservatório como as β-α mesasaprobic (βms- αms), considerado crítico quanto o teor de matéria orgânica. O índice BMWP foi adaptado para os pontos de coleta e subsequentemente as pontuações foram obtidas classificando o reservatório como de categoria V (qualidade muito ruim). O índice ICB $_{RES-P}$ classificou a qualidade da água nos pontos de coleta do período de primavera/verão como regular, e no período de outono/inverno como boa. **Conclusões:** A partir dos resultados obtidos pode-se concluir que são necessários mais estudos e refinamentos dos componentes de ambos os índices para determinar com eficiência a qualidade da água em reservatórios.

Palavras-chave: biomonitoramento; macroinvertebrados bentônicos; índice BMWP; índice ICB $_{RES-P}$; Reservatório de Itupararanga.

1. Introduction

The increase in anthropogenic activities in recent decades has intensified pressure on water resources. Nowadays there are very few aquatic or land ecosystems that have not suffered the direct and/or indirect influence of human activities (Goulart & Callisto 2003; Valipour 2014a, b, c, 2015; Valipour et al., 2015). As water is a key natural resource for establishing and maintaining life, several methodologies have been developed in order to determine and diagnose the environmental impacts and disturbances that result from human activities (Buss et al. 2003). One of these is the biomonitoring of aquatic organisms, such as benthic macroinvertebrates (Rosenberg et al., 1999; Egler et al., 2012; Coe et al., 2013, Feio et al., 2014; Smetanová et al., 2014).

To improve and shorten the time needed to evaluate the quality of aquatic environments, biotic indexes have been created based on the conception of the sensitivity and tolerance of benthic macroinvertebrates in response to different impacts (Cairns Junior & Pratt, 2000). Among the indexes that are currently used to investigate the water quality of aquatic ecosystems, analysis of benthic macroinvertebrate biota using the BMWP (Biological Monitoring Working Party score system) index can be highlighted. The BMWP index was created in England in 1976 (Hawkes, 1997) based on the premise of being easy to use and quick to operate. The index is based on the scores given to the families of benthic macroinvertebrates, with the sum of the scores of these organisms used to determine the quality of the ecosystems (Hawkes, 1997). The BMWP index has been widely used in the United Kingdom to characterize the quality of rivers, streams and creeks (Metcalfe, 1989), as well as in other countries (López et al., 2005) such as Brazil (Junqueira & Campos, 1998; Junqueira et al., 2000; Monteiro et al., 2008; Roche et al., 2010; Ruaro et al., 2010).

Another biotic index that uses benthic macroinvertebrates as bioindicators of aquatic environments through scoring is the Benthic Community Index (ICB), which was created by CETESB (Environmental Sanitary Company of the State of São Paulo) (CETESB, 2012). This index is a multimetric with different and specific versions used for each type of system to be analyzed. It has already been used in some studies (Yoshida & Rolla, 2012;

Yoshida & Uieda, 2013), which demonstrated its effectiveness in the detection and characterization of the quality of the environments studied.

The Itupararanga Reservoir is located in the southwest region of the state of São Paulo, Brazil, in an environmental protection area (Figure 1). This reservoir is important as it provides water supply to the population and power generation to industry. The rivers responsible for supplying the reservoir have suffered a degree of human impact due to the removal of riparian vegetation, the entry of untreated domestic sewage, and demographic pressure (Cunha & Calijuri, 2011). These impacts on the reservoir drainage basin can be classified as between minimum and high (Salles et al., 2008).

It is important to note that the Itupararanga Reservoir has been the subject of a number of studies with different focuses (Conceição et al., 2011; Bottino et al., 2013; Beghelli et al., 2014). All the studies conducted so far have shown that the quality of water of the reservoir has been declining (Salles et al., 2008; Beghelli et al., 2012; Beghelli et al., 2014; Beghelli et al., 2016). None of the earlier conducted studies using macroinvertebrates as bioindicators have focused on the tributaries regions of the Itupararanga Reservoir, which are more densely occupied, and neither to have focused on test which is the most effective and applicable biotic index to determine the water quality. To enlighten this gaps the aim of this study was therefore to apply two biological indexes based on benthic macroinvertebrates (BMWP and ICB $_{RES-P}$) to answer the following question: What are the advantages and disadvantages of application of each index in a reservoir? The answers to this question will improve the use and applicability of these indexes for future biomonitoring of similar lentic environments.

2. Materials and Methods

The present study consisted of three distinct stages: 1) macroinvertebrate sampling and determination of water variables *in situ*, followed by sorting of the organisms in the laboratory, 2) taxonomic identification of the organisms, and, 3) determination of the saprobic degree of the collection sites and the adequacy of the BMWP index and the CETESB benthic community index for reservoirs (ICB$_{RES-P}$). Samplings were carried out in the Itupararanga Reservoir over two seasons: spring/summer (October to December of 2013 and January to February of 2014) using nine stations, and autumn/winter (June to September of 2014) using eight stations (Figure 2). The sampling stations were preferably located in the tributaries of the left bank of the reservoir, which are more densely occupied areas. These stations were georeferenced, and their geographic coordinates are listed in Table 1. The reservoir was divided into three zones: riverine, near the tributaries; transitional, in the middle of the reservoir; and lacustrine, close to the dam. According to Thornton et al. (1982), in a reservoir these zones occur due to differences in the limnological characteristics of each region. The division between the zones of the Itupararanga Reservoir was proposed by Beghelli et al. (2012).

Benthic macroinvertebrates were sampled using a modified Peterson dredge. Cumulative samples were taken at several times, until 10 L of sediment had been collected. The sediment was washed in the laboratory with running water with sieves with a 250 µm mesh screen to remove excess material, and was transferred to translucent plastic trays in a box with fluorescent lighting to facilitate the visualization of the organisms. After sorting, the specimens were preserved in 70% alcohol,

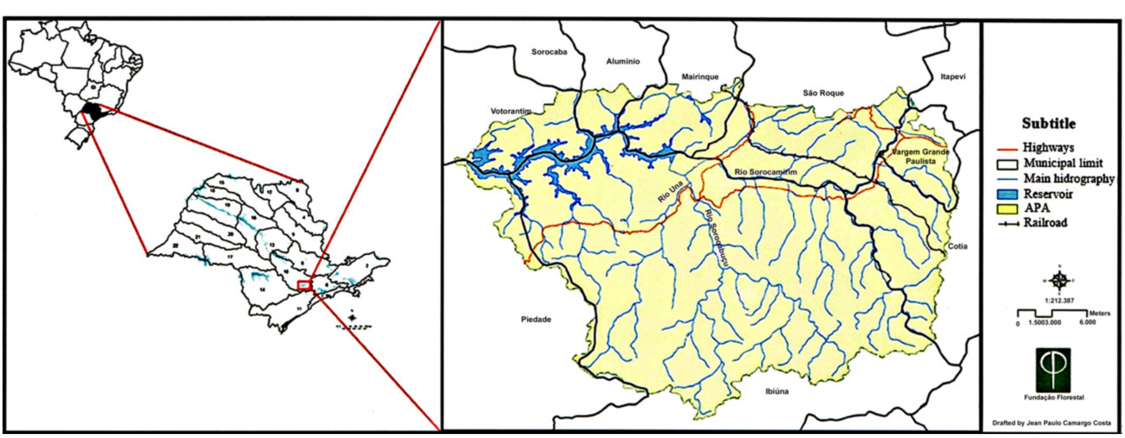

Figure 1. Localization of Itupararanga Reservoir in an environmental protection area, State of São Paulo, Brazil.

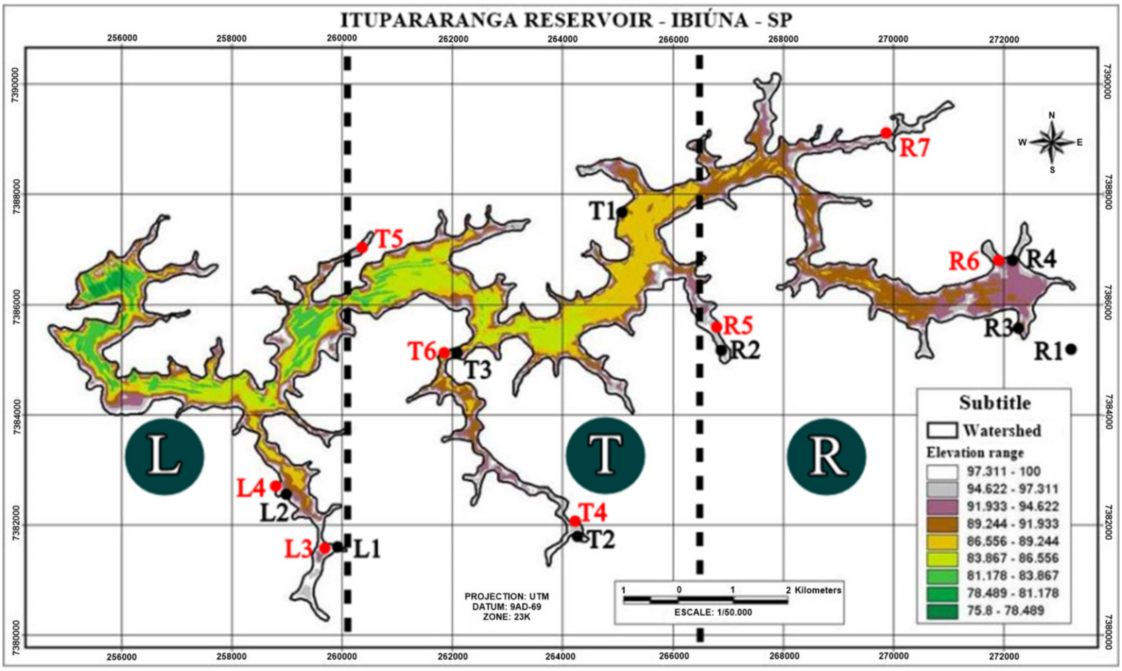

Figure 2. Sampling points localization during the spring/summer (in black) and autumn/winter (in red) respecting the particular zonation determined by Beghelli et al. (2012). L = Lacustrine zone; T = Transitional zone; R = Riverine zone. Source: Modified of Beghelli et al. (2014).

Table 1. Sampling stations and their geographic coordinates.

Station	Zone	Date	Latitude (S)	Longitude (W)
R1	Riverine	25/10/2013	23° 38' 13.3"	47° 13' 06.7"
T1	Transitional	08/11/2013	23° 36' 24"	47° 18' 15.1"
R2	Riverine	08/11/2013	23° 37' 38.2"	47° 17' 2.3"
R3	Riverine	27/11/2013	23° 38' 06.6"	47° 13' 56.0"
L1	Lacustrine	08/01/2014	23° 39' 30.8"	47° 21' 06.4"
L2	Lacustrine	05/02/2014	23° 38' 55"	47° 21' 48.7'
R4	Riverine	12/02/2014	23° 36' 54.2 "	47° 14' 01.5"
T2	Transitional	19/02/2014	23° 39' 21.2"	47° 18' 37.4"
T3	Transitional	19/02/2014	23° 37' 46.1"	47° 20' 02.7"
R5	Riverine	23/07/2014	23° 37' 24.3"	47° 17' 09. 4"
R6	Riverine	23/07/2014	23° 36' 52.9"	47° 14" 04.11"
T4	Transitional	06/08/2014	23° 39" 04.1"	47° 18" 52.3"
L3	Lacustrine	20/08/2014	23° 39' 37.7"	47° 21' 24.6"
L4	Lacustrine	20/08/2014	23° 38' 55.7"	47° 21'47.9"
T5	Transitional	27/08/2014	23° 36' 31.5"	47° 20' 52.9 "
T6	Transitional	27/08/2014	23° 37' 42.40"	47° 20' 04.9"
R7	Riverine	03/09/2014	23° 35' 31.6"	47° 15' 14.2"

counted and identified through specialized literature (Brinkhurst & Gelder, 2001; Mungnai, 2010; Trivinho-Strixino, 2011). In general, identification was carried out to family level. Individuals of the Chironomidae family (Diptera) were identified to genus level, molluscs to species level and Oligochaeta individuals were separated into two morphotypes. The organisms were deposited in the Benthic Macroinvertebrates Collection of the Biology Department of the Human and Biological Science Center of the Federal University of São Carlos, Sorocaba Campus, Brazil.

The regional adaptation of the BMWP model involved the calculation of a new score for each family of macroinvertebrates present in the reservoir. The saprobiotic valences of the macroinvertebrate families were determined by correlating the frequencies of occurrence with the different levels of saprobity of each sampling station. The saprobiotic levels for the sampling stations were obtained using the reference values provided by Junqueira & Campos (1998) (Table 2), which, in turn, were adapted from the saprobiotic degrees proposed in the Richtlinie für die Ermittlung der Gewässergüte-Klasse ("Guidelines for Determining Water Quality Class") manual, created by Kolkwitz & Marsson (1909).

The parameters dissolved oxygen (OD), biochemical oxygen demand (BOD5) and chemical oxygen demand (COD) were selected as a basis for this study. The dissolved oxygen was determined *in situ* using an YSI 556 multi-probe. A HACH kit, which is based on the oxidation of the organic matter present in the samples by reaction with a chemical agent (potassium dichromate), was used to measure COD. After the digestion of the solution in a dry block, COD measurement was performed using the colorimetric method by spectrophotometry (model DL 5000, HACH). BOD5 was determined by the 5-day BOD protocol, which employs the technique of incubation with dilution, according to the technical standards established by the Brazilian Association of Technical Standards (ABNT, 1992).

To perform the determination and adequacy of the biotic indexes, the sampling points were organized in two ways: 1) according to temporal variation (spring/summer and autumn/winter) and 2) according to the spatial variation of the sampling points along the dam, considering the zonation of the reservoir. After the identification of the organisms and tabulation of their sampling station, the frequency of occurrence of each family was correlated with saprobiotic level, and new scores were obtained using the following Equation 1:

$$Si = \sum_{j=1} \frac{nij \times Vi}{ni} \quad (1)$$

In this equation S_i is the score for the family i, n_{ij} is the family abundance for i in location with saprobic degree j, V_j is the value weighted to this saprobiotic degree and n_i is the total family abundance. The weighting values used were: 10 for Os (Oligosaprobic), 5 for Os-βms (Oligo-β-mesosaprobic), 4 for βms (β-mesosaprobic), successively decreasing to 0 for Ps (Polisaprobic). From the BMWP index obtained in this study, score ranges to determine the classes of water quality (excellent, good, satisfactory, poor, and very poor) for each sampling station were proposed (Alba-Tercedor & Jiménez-Millá, 1987). This classification facilitates the visualization of biomonitoring results, as it allows graphical representation (Junqueira et al., 2000).

There are several versions of the Benthic Community Index (ICB), with each version related to a specific type of water environment. In the present study, considering the characteristics presented by the sampled community, the ICB_{RES-P} (Benthic Community index for Deep Regions of Reservoirs) was applied. To calculate the index, the richness of the benthic macroinvertebrates community (S), Shannon-Wiener diversity (H'), Tanytarsini/Chironomidae ratio (Tt/Chi) from community density, and tolerant group dominance (T/DT, where: T = tolerance density and DT = total density of the sample organisms) were applied. The individuals from the *Chironomus*

Table 2. Reference values to saprobiotic levels, based on physical and chemical parameters (Junqueira & Campos, 1998). Sat Def. (Saturation defiance), Super Sat. (Super Saturation), COD (Chemical oxygen demand) and BOD (Biochemical oxygen demand).

Classes	Saprobic level	Saprobic index	Degree of Organic pollution	OD (%) Sat Def.	OD (%) Super Sat.	BOD5 (mg/L)	$NO2^{-}$ (mg/L)	COD (mg/L)
I	Oligosaprobic (Os)	1.0 to < 1.5	Absent and scarce	0 to 5	0 to 3	0 to 0.5	<0.1	1 to < 3
I-II	Oligo-β-mesosaprobic (Os-βms)	1.5 to < 1.8	Scarce	5 to 15	3 to 10	0.5 to 2.0	0.1	3 to < 6
II	β-mesosaprobic (βms)	1.8 to < 2.3	Moderate	15 to 30	10 to 25	2.0 to 4.0	>0.1 to 0.3	6 to < 10
II-III	β-α mesasaprobic (βms-αms)	2.3 to < 2.7	Problematic	30 to 50	25 to 50	4.0 to 7.0	0.3 to < 0.7	10 to < 19
III	α - mesosaprobic (αms)	2.7 to < 3.2	High	50 to 75	50 to 100	7.0 to 13.0	0.7 to < 0.3	19 to < 75
III-IV	α - meso- polisaprobic (αms-ps)	3.2 to < 3.5	Very high	75 to 90	>100	13.0 to 22.0	0.3 to < 9	>75
IV	Polisaprobirc (Ps)	3.5 to 4.0	Excessive	>90	-	>22.0	>9	>75

and Tubificidae family without capillary bristles are considered tolerant in these reservoirs (CETESB, 2012). The final score was achieved from the arithmetic average value obtained from the sum of each metric of the sampling stations, and this score was used to classify the water quality. The scores obtained for each sampling station were classified according to the CETESB protocol (Table 3) (CETESB, 2012).

3. Results

During the two study periods 8,841 individuals were sampled, which were classified into 17 taxa, with the *Chaoborus* (Chaoboridae), Chironomidae (subfamilies Chirominae and Tanypodinae) and Tubificidae the most abundant. The saprobic level of each sampling station was calculated from chemical parameters (Table 4). The reservoir was, therefore, in general classified as the β-α mesasaprobic (βms-αms), which is considered critical due to its high organic charge content.

The BMWP index was adapted for the Itupararanga Reservoir, and new scores were established for each sampling station based on the saprobiotic level measured (Table 5), as well as the frequency of occurrence of the identified organisms (Figures 3 and 4). Although scores are usually determined through taxonomic identification only to family level, in case the genus level was established for many taxa, mainly Chironomidae. After obtaining the scores for the identified taxa, the sum of scores was calculated and the rank for each sampling station in Itupararanga Reservoir was obtained (Table 6). The water quality was classified as category V, or in other words very poor, irrespective of the zone.

The ICB_{RES-P} index classified the study sites in the spring/summer period as having regular water quality. In the autumn/winter period, however, an improvement in the water quality of most sample points was observed, and the water of the reservoir was considered to be of good quality (Table 7).

4. Discussion

The saprobiotic degrees measured demonstrated that these environments are undergoing a process of degradation, a finding which corroborates the expected results for the riverine zone (βms-αms

Table 3. Water quality classification for Benthic Community Index (ICB_{RES-P}) based on CETESB protocol (CETESB, 2012).

Class	Scores	S	H'	T/DT	Tt/Chi
Very poor	5		AZOIC		
Poor	4	1 to 3	≤ 0.5	≥ 0.8	≤ 0.03
Regular	3	4 to 6	> 0.5 to ≤ 1.5	≥ 0.5 to < 0.8	> 0.03 to ≤ 0.06
Good	2	7 to 9	> 1.5 to ≤ 2	≥ 0.2 to < 0.5	> 0.06 to < 0.1
Great	1	≥ 10	> 2	< 0.2	≥ 0.1

Table 4. Saprobic levels of the sampling stations studied in the Itupararanga Reservoir.

Stations	Classes	Saprobic levels	Degree of Organic pollution	Seasonal period
R1	II-III	β-α mesasaprobic (βms-αms)	Problematic	Spring/summer
R2	II-III	β-α mesasaprobic (βms-αms)	Problematic	
R3	III	α - mesosaprobic (α ms)	High	
R4	III	α - mesosaprobic (α ms)	High	
T1	II	β-mesosaprobic (βms)	Moderate	
T2	II	β-mesosaprobic (βms)	Moderate	
T3	II-III	β-α mesasaprobic (βms-αms)	Problematic	
L1	III	α - mesosaprobic (α ms)	High	
L2	II-III	β-α mesasaprobic (βms-αms)	Problematic	
R5	II-III	β-α mesasaprobic (βms-αms)	Problematic	Autumn/winter
R6	III	α - mesosaprobic (α ms)	High	
R7	III	α - mesosaprobic (α ms)	High	
T4	II	β-mesosaprobic (βms)	Moderate	
T5	II-III	β-α mesasaprobic (βms-αms)	Problematic	
T6	II-III	β-α mesasaprobic (βms-αms)	Problematic	
L3	II-III	β-α mesasaprobic (βms-αms)	Problematic	
L4	III	α - mesosaprobic (α ms)	High	

Table 5. Scores assigned to each taxon of benthic macroinvertebrates in Itupararanga Reservoir.

Taxon	Scores
Subclass Acari	4
Genus *Chaoborus*	2
Subfamily Ceratopogoidae	2
Genus *Asheum*	3
Genus *Cladopelma*	3
Genus *Chironomus*	2
Genus *Fissimentum*	3
Genus *Pelomus*	1
Genus *Polypedilum*	1
Genus *Saetheria?*	3
Genus *Tanytarsus*	2
Genus *Tanypus*	2
Melanoides tuberculatus (Müller, 1774)	2
Pomacea figulina (Spix in Wagner, 1827)	2
Family Tubificidae 1	1
Family Tubificidae 2	1
Genus *Helobdella*	2

and α ms degrees), but which is perhaps surprising for the lacustrine zone. This suggests that the L1, L2, L3 and L4 sampling stations with respectively of α ms, βms-αms, βms-αms and α ms saprobic degrees are receiving diffuse organic matter from domestic and/or agricultural sewage, consistent with the holiday homes and farms near the reservoir.

The use of biological indicators of water quality to monitor watersheds is widely used in European countries, and has been included in national technical standards in several countries (Junqueira et al., 2000). As the saprobity (pollution levels) of rivers can be used as a measure of contamination resulting from the reduction of dissolved oxygen in the water, and as it directly affects the biota, different biological indexes for the assessment of water quality have been created (Monteiro et al., 2008).

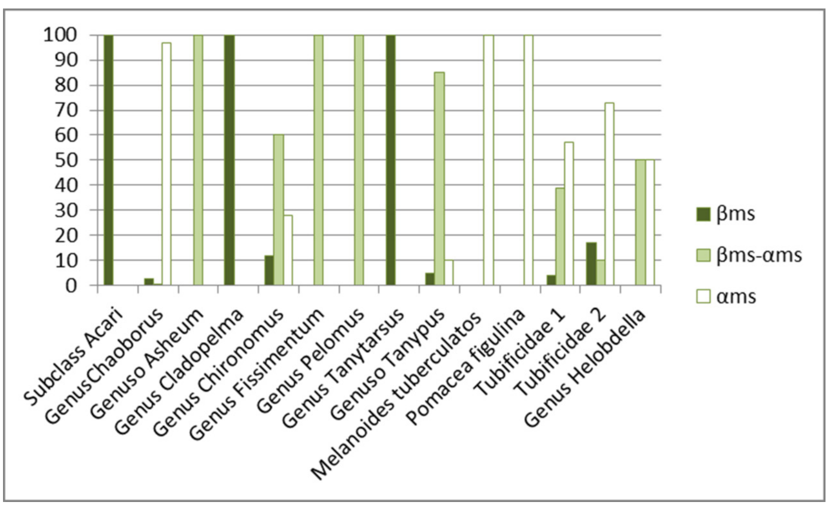

Figure 3. Frequency of occurrence of identified organisms of benthic macroinvertebrates according to saprobiotic levels for spring/summer station.

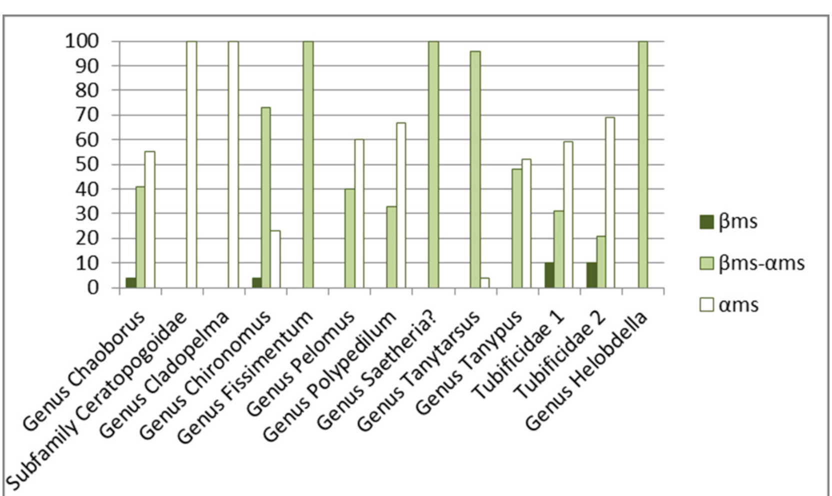

Figure 4. Frequency of occurrence of identified organisms of benthic macroinvertebrates according to saprobiotic levels for autumn/winter station.

Table 6. Values of the adapted BMWP and water quality ranking system based on benthic macroinvertebrates to the sampling stations of Itupararanga.

Sampling Station	Sum scores	Rank	Quality	Seasonal period
R1	8	V	Very Poor	Spring/ summer
R2	5			
R3	6			
R4	6			
T1	9			
T2	13			
T3	14			
L1	14			
L2	7			
R5	11	V	Very Poor	Autumn/ winter
R6	6			
R7	13			
T4	6			
T5	14			
T6	15			
L3	10			
L4	12			

Table 7. Water quality ranking system based on benthic macroinvertebrates for each sampling station, zone and seasonal period obtained with ICB_{RES-P} index.

Station	Quality	Quality for Zone	Seasonal period
R1	Regular	Regular	Spring/ summer
R2	Regular		
R3	Poor		
R4	Good		
T1	Regular	Regular	
T2	Good		
T3	Regular		
L1	Regular	Regular	
L2	Regular		
R5	Good	Regular	Autumn/ winter
R6	Regular		
R7	Regular		
T4	Regular	Good	
T5	Good		
T6	Good		
L3	Regular	Good	
L4	Good		

These indexes assign increasing values to organisms according to their tolerance to pollution. In an attempt to unify the methodology employed in each country, the BMWP (Biological Monitoring Working Party score system) was developed, which uses macroinvertebrates identified to the family taxonomic level, notably insects, which are the most numerous of such macroinvertebrates (Monteiro et al., 2008). In Brazil, the BMWP index has been adapted and used to determine the water quality of the watershed of the Rio das Velhas river in the state of Minas Gerais (Junqueira et al., 2000), and also the watershed of the Rio Meia Ponte river in the state of Goiás (Monteiro et al., 2008). In these watersheds, the BMWP has proved to be a highly effective method of monitoring water resources. However, Monteiro et al. (2008) emphasize that there is a need to adapt the biotic values of BMWP to local and regional conditions, as the BMWP tool was created for environments in temperate zones. Indeed, environmental change processes vary according to the history of human occupation around the watershed to be monitored.

The BMWP index was adapted to the Itupararanga Reservoir by establishing new scores based on the saprobic degrees obtained for the sampling stations, and the frequencies of occurrence, and abundance of the collected benthic macroinvertebrates. Despite the adjustments being performed to family levels, genus and species levels were also employed for hexapods and molluscs, and the oligochaetes were classified into two morphotypes. These adjustments were performed due to the fact that the values originally assigned to families in the BMWP list, as well as other studies, are calculated for lotic environments and, therefore, do not reflect the conditions of tropical reservoirs. The richness and diversity of organisms in reservoirs is known to be lower than those observed in rivers and streams, and the species that occur in this environment are, naturally, more tolerant to pollutants (Goulart & Callisto, 2003; Tundisi & Tundisi, 2008).

Despite the use of lower taxonomic levels, the BMWP index ranked all the sampling stations as category V, representing a water quality of very poor. Furthermore, considering that the BMWP index was originally designed for rivers and streams with a naturally higher diversity and richness of organisms, quite different from those presented in reservoirs and lakes, the BMWP index should also be adapted to the context of tropical reservoirs, which are mainly composed of organisms known to be indicators of impacted environments, such as Chironomidae and Oligochaeta. These organisms groups have shown high frequency of occurrence in almost of the sample points with βms-αms and α ms saprobic degrees considered respectively as critical and problematic due to its organic charge content levels. But in these environments such organisms constitute a large part of the community and are not solely a sign of the depletion of water quality and the environment as observed in the T1 and T2 sampling stations (βms saprobic degree/moderate organic charge content level). However, this index has the advantage of combining abiotic and biological data, providing a wider analysis of the study environment and a realistic profile of the quality of the water.

In searching for an index that did not suffer too much interference from the changes caused by the low diversity of in the studied sites, which is expected for reservoirs, the benthic community index for deep regions of reservoirs (ICB_{RES-P}) was selected and compared to the BMWP index, in order to provide a comparative analysis between the results obtained for the quality and integrity of the study sites. Although both indexes are based on the premise of determining the water quality of aquatic environments from scores obtained from calculations, the ICB index, in contrast to the BMWP index, does not include the saprobic degree of the site in the analysis, being based only on the constitution of the benthic macroinvertebrate community. The ICB index classified the reservoir as having water of regular quality in spring/summer and good in the autumn/winter, indicating there was a noticeable improvement in the quality of water in the autumn/winter period. This index also demonstrated that the riverine zone had worse water quality than the lacustrine and transitional zones during the autumn/winter season.

In southeast Brazil, there are two conspicuous seasons, the rainy (spring/summer), and the dry (autumn/winter). The horizontal stratification in reservoirs is less evident in rainy seasons, when water quality was considered regular by the ICB index. During the dry season, considering that there is less sediment entering the reservoir from adjacent areas and also that the quantity of organic matter and resuspended sediment is lower (Tundisi et al., 1999), the diversity of the benthic macroinvertebrate community increases, which can explain the classification of the water quality in the reservoir by the ICB index as good in the autumn/winter. Furthermore, during dry seasons in tropical environments, macroinvertebrates, especially insects, are already in an advanced developmental stage, and are therefore easier to sample (Merrit & Cummins, 1996). Nevertheless, the ICB index, despite being created to characterize tropical reservoirs, was found to give a restrictive analysis of the study environment, as it only considers the benthic macroinvertebrate community, and does not employ abiotic data. As a consequence, if only the ICB index was employed, it would provide the impression that during the autumn/winter period the water quality was better than the rainy period, mainly because of the ease of collecting macroinvertebrates (insects) in an advanced developmental stage. It is expected that during the dry season there is deterioration in water quality due to the increased system stability of tropical reservoirs (Tundisi et al., 1999). Therefore, the ICB index must be applied restrictively to one season of the year.

5. Conclusions

In summary, it can be concluded that both indexes are different and that neither is truly perfect in its analysis. Further study and refinement of the components of the indexes are required in order to effectively assess the quality of water in reservoirs, especially when located in tropical regions. For the BMWP index is essential not only to adjust the score of the taxa for each site, but also to modify the weightings applied to saprobic degree in reservoirs. The ICB index, meanwhile, should be applied restrictively to one season per year, or also employ abiotic data in its calculations of water quality, in order to provide more accurate results.

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References

ALBA-TERCEDOR, J. and JIMÉNEZ-MILLÁN, F. *Evaluación de las variaciones estacionales de la calidad de las aguas del río Guadalfeo, basado em el estúdio de las comunidades de macroinvertebrados acuáticos*. Madrid: Instituto Nacional para la Conservacion de la Naturaleza, 1987. Lucdeme III. Icona Monografia, 48.

ASSOCIAÇÃO BRASILEIRA DE NORMAS TÉCNICAS – ABNT. *NBR 12614: águas: determinação da demanda bioquímica de oxigênio (DBO): método de incubação (20 °C, cinco dias)*. Rio de Janeiro: ABNT, 1992.

BEGHELLI, F.G.S., SANTOS, A.C.A., URSO-GUIMARÃES, M.V. and CALIJURI, M.C. Relationship between space distribution of the benthic macroinvertebrates community trophic state in a Neotropical reserv*oir (Itupararang*a, Brazil). *Biota Neotropica*, 2012, 12(4), 1-12.

BEGHELLI, F.G.S., SANTOS, A.C.A., URSO-GUIMARÃES, M.V. and CALIJURI, M.C. Spatial and temporal heterogeneity in a subtropical reservoir and their effects over the benthic m*acroinvertebrate community. Acta Limnologica Brasiliensia*, 2014, 26(3), 306-317.

BEGHELLI, F.G.S., FRASCARELI, D., POMPÊO, M.L.M. and MOSCHINI-CARLOS, V. Trophic state evolution over 15 years in a Tropical Reservoir with low nitrogen concentrations and cyanobacteria predominance. *Water, Air, and Soil Pollution*, 2016, 227(3), 95. http://dx.doi.org/10.1007/s11270-016-2795-1.

BOTTINO, F., CALIJURI, M.C. and MURPHY, K.J. Temporal and spatial variation of limnological variables and biomass of diferente macrophyte species in a Neotropical reservoir (São Paulo – Brazil). *Acta Limnologica Brasiliensia*, 2013, 25(4), 387-397. http://dx.doi.org/10.1590/S2179-975X2013000400004.

BRINKHURST, R.O. and GELDER, S.R. Annelida: Oligochaeta including Branchiobidellidae. In J.H. THORP and A.P. COVICH. *North American freshwater invertebrate.* Orlando: Academic Press, 2001, pp. 431-463.

BUSS, D.F., BAPTISTA, D.F. and NESSIMIAN, J.L. Bases conceituais para a aplicação de biomonitoramento em programas de avaliação da qualidade da água de rios. *Cadernos de Saude Publica*, 2003, 19(2), 465-473. PMid:12764462. http://dx.doi.org/10.1590/S0102-311X2003000200013.

CAIRNS JUNIOR, J. and PRATT, J.R. A history of biological monitoring using benthic macroinvertebrates. In D.M. ROSENBERG and V.H. RESH, eds. *Freshwater biomonitoring and benthic macroinvertebrates.* New York: Chappman & Hall, 2000, pp. 10-27.

COMPANHIA DE TECNOLOGIA DE SANEAMENTO AMBIENTAL – CETESB. *Protocolo para o biomonitoramento com as comunidades bentônicas de rios e reservatórios do estado de São Paulo*. São Paulo: CETESB, 2012 [viewed 11 Jan. 2014]. Available from: http://www.cetesb.sp.gov.br/agua/aguas-superficiais/35-publicacoes-/-relatorios

COE, H.J., WEI, X. and KIFFNEY, P.M. Linking forest harvest and landscape factors to benthic macroinvertebrate communities in the interior of British Columbia. *Hydrobiologia*, 2013, 717, 65-84.

CONCEIÇÃO, F.T., SARDINHA, D.S., NAVARRO, G.R.B., ANTUNES, M.L.P. and ANGELUCCI, V.A. Composição química das águas pluviais e deposição atmosférica anu*al na bacia do Alto* Sorocaba (SP). *Química Nova*, 2011, 34(4), 610-616. http://dx.doi.org/10.1590/S0100-40422011000400011.

CUNHA, D.F. and CALIJURI, M.D. Limiting factors for phytoplankton growth in subtropical reservoirs: the effect of light and nutrient availability in different longitudinal compartments. *Lake and Reservoir Management*, 2011, 27(2), 162-172. http://dx.doi.org/10.1080/07438141.2011.574974.

EGLER, M., BUSS, D.F., MOREIRA, J.C. and BAPTISTA, D.F. Influence of agricultural land-use and pesticides on benthic macroinvertebrate assembles in an agricultural river basin in sout*heast Brazil. Brazilian Journal of Biolology*, 2012, 72(3), 437-443. http://dx.doi.org/10.1590/S1519-69842012000300004.

FEIO, M.J., FERREIRA, J., BUFFAGNI, A., ERBA, S., DÖRFLINGER, G., FERRÉOL, M., MUNNÉ, A., PRAT, N., TZIORTZIS, I. and URBANIČ, G. Comparability of ecological quality boundaries in the Mediterranean basin using freshwater benthic invertebrates. Statica*l options and implications. Science of Total Environment*, 2014, 476/477, 777-784. http://dx.doi.org/10.1016/j.scitotenv.2013.07.085.

GOULART, M. and CALLISTO, M. Bioindicadores de qualidade de água como ferramenta em estudos de impacto ambiental. *Revista da FAPAMA*, 2003, 2(1), 156-164.

HAWKES, H.A. Origin and development of the biological monitoring working party score system. *Water Research*, 1997, 32, 964-968. http://dx.doi.org/10.1016/S0043-1354(97)00275-3.

JUNQUEIRA, M.V. and CAMPOS, S.C.M. Adaptation of the "BMWP" method for water quality evaluation to Rio das Velhas watershed (Minas Ger*ais, Brasil). Acta Limnologica Brasiliensia*, 1998, 10(2), 125-135.

JUNQUEIRA, M.V., AMARANTE, M.C., DIAS, C.F.S. and FRANÇA, E.S. Biomonitoramento da qualidade das águas da Bacia do Alto Rio das Velhas (MG/Brasil) através de macroinvertebrados. *Acta Limnologica Brasiliensia*, 2000, 12, 73-87.

KOLKWITZ, R. and MARSSON, M. Oekologie der tierischen Saprobien. Beiträge zur Lehre von der biologischen Gewässerbeurteilung. *Internationale Revue der Gesamten Hydrobiologie und Hydrographie*, 1909, 2, 126-152. http://dx.doi.org/10.1002/iroh.19090020108.

LÓPEZ, C.N., LAZO, D.D.G., GONZÁLES, G.G., BRANDIMARTE, A.L., RIVEAUX, S.M. and CORDERO, Y.M. Una metodologia rápida y de fácil aplicación para la evaluación de la calidad del agua utilizando el índice BMWP-Cub para ríos cubanos. Com-ciencias. *Tecnura*, 2005, 9(17), 65-76.

MERRIT, W. and CUMMINS, K.W. *An introduction to the aquatic insects of North America*. 3rd ed. Iowa: Kendall/Hunt Publishing Company, 1996.

METCALFE, J.L. Biological water quality assessment of running waters based on macroinvertebrates communities: history and present status in Europe. *Environmental Pollution*, 1989, 60(1-2), 101-139. PMid:15092393. http://dx.doi.org/10.1016/0269-7491(89)90223-6.

MONTEIRO, T.R., OLIVEIRA, L.G. and GODOY, B.S. Biomonitoramento da qualidade de água utilizando macroinvertebrados bentônicos: adaptação do índice biótico BMWP à bacia do Rio Meia Ponto-GO. *Oecologia brasiliensis*, 2008., 12(3), 553-563.

MUNGNAI, R. *Manual de identificação de macroinvertebrados aquáticos do Estado do Rio de Janeiro.* Rio de Janeiro: Technical Books, 2010.

ROCHE, K.F., QUEIROZ, E.P., RIGHI, K.O. and SOUZA, G.M. Use of the BMWP and ASPT indexes for monitoring environmental quali*ty in a neotropical stream. Acta Limnologica Brasiliensia*, 2010, 22(1), 105-108. http://dx.doi.org/10.4322/actalb.02201010.

ROSENBERG, D.M., REYNOLDSON, T.B. and RESH, V.H. *Establishing reference conditions for benthic invertebrate monitoring in the Fraser River Catchment, British Columbia, Canada*. Vancouver: University of California, 1999.

RUARO, R., AGUSTINI, M.A.B. and ORSSATTO, F. Avaliação da qualidade da água do Rio Clarito no município de Cascavel (PR), através do índice BMWP adaptado. *Revista Saúde e Biologia*, 2010, 5, 5-12.

SALLES, M.H.D., CONCEIÇÃO, F.T., ANGELUCCI, V.A., SIA, R., PEDRAZZI, F.J.M., CARRA, T.A., MONTEIRO, G., SARDINHA, D.S. and NAVARRO, G.R.B. Avaliação simpl*ificada de impactos ambientai*s na Bacia do Alto Sorocaba (SP). *Revista de Estudos Ambientais*, 2008, 10(1), 6-20.

SMETANOVÁ, S., BLÁHA, L., LIESS, M., SCHÄFER, R.B. and BEKETOV, M.A. Do predictions from Species Sensitivity Di*stributions match with* field data? *Environmental Pollution*, 2014, 189, 126-133. PMid:24657606. http://dx.doi.org/10.1016/j.envpol.2014.03.002.

THORNTON, K.W., KENNEDY, R.H., MAGOUN, A.D. and SAUL, G.E. Reservoir water quality sampling design. *Journal of the American Water Resources Association*, 1982, 18(3), 471-480. http://dx.doi.org/10.1111/j.1752-1688.1982.tb00014.x.

TRIVINHO-STRIXINO, S. *Larvas de Chironomidae.* São Carlos: Departamento Hidrobiologia/Laboratório de Entomologia Aquática/UFSCar, 2011.

TUNDISI, J.G. and TUNDISI, T.M. *Limnologia*. São Paulo: Oficina de Textos, 2008.

TUNDISI, J.G., MATSUMURA-TUNDISI, T. and ROCHA, O. Theorical basis for Reservoir Management. In J.G. TUNDISI and M. STRASKRABA, eds. *Theorical Reservoir Ecology and its applications.* Kerkwerve: Backhuys Publishers, 1999, pp. 505-528.

VALIPOUR, M. Future of the area equipped for irrigation. *Archives of Agronomy and Soil Science*, 2014a, 60(12), 1641-1660. http://dx.doi.org/10.1080/03650340.2014.905675.

VALIPOUR, M. Drainage, waterlogging, and salinity. *Archives of Agronomy and Soil Science*, 2014b, 60, 1625-1640. http://dx.doi.org/10.1080/03650340.2014.905676.

VALIPOUR, M. A comprehensive study on irrigation management in Asia and Oceania. *Archives of Agronomy and Soil Science*, 2014c, 61(9), 1247-1271. http://dx.doi.org/10.1080/03650340.2014.986471.

VALIPOUR, M., ZIATABAR AHMADI, M., RAEINI-SARJAZ, M., GHOLAMI SEFIDKOUHI, M.A., SHAHNAZARI, A., FAZLOLA, R. and DARZI-NAFTCHALI, A. Agricultural water management in the world during past half century. *Archives of Agronomy and Soil Science*, 2015, 61(5), 657-678. http://dx.doi.org/10.1080/03650340.2014.944903.

VALIPOUR, M. Future of agricultural water management in Africa. *Archives of Agronomy and Soil Science*, 2015, 61(7), 907-927. http://dx.doi.org/10.1080/03650340.2014.961433.

YOSHIDA, C.E. and ROLLA, A.P.P.R. Ecological attributes of benthic community and indices of water quality in urban, rural and preserved *environments. Acta Limnologica Brasiliensia*, 2012, 24(3), 235-243. http://dx.doi.org/10.1590/S2179-975X2012005000041.

YOSHIDA, C.E. and UIEDA, V.S. Índices bióticos mono e multimétricos de avaliação da qualidade da água em riachos de Mata Atlântica. *Biokos*, 2013, 27(2), 79-88.

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